SELF-CONTAINED MICROMECHANICAL VENTILATOR

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BACKGROUND OF THE INVENTION

Immediate medical care can save the lives of countless accident victims and military personnel. In the emergency medical services arena, there has long been an emphasis on the golden hour during which a patient must receive definitive medical attention. However, definitive medical attention is often limited, because of the lack of necessary equipment. While state of the art medical equipment can be found in medical facilities, such is not the case in emergency situations or military applications. This is particularly true in the area of ventilators.

Inspiration-only ventilators are known and widely used in hospital settings as they provide useful breathing circuits while minimizing the amount of oxygen utilized in treating the patient.

Current ventilators are generally designed for stationary, medical facilities. They are heavy, cumbersome and ill suited for portable applications. Most ventilators utilize medical grade air or highly flammable, compressed

canisters of oxygen for its oxygen sources. These tanks air/oxygen are heavy, cumbersome, and unsuitable for transport. Prior-art ventilators also require large power sources, making them even less suitable for quick, on-site use. Lastly, most known ventilators require operation by trained personnel in treatment environments, where additional equipment and resources are easily available.

For example, U.S. Patent 5,664,563 to Schroeder, et al., disclose a computer controlled pneumatic ventilator system that includes a double venturi drive and a disposable breathing circuit. The double venturi drive provides quicker completion of the exhalation phase leading to an overall improved breathing circuit. The disposable breathing circuit allows the ventilator to be utilized by multiple patients without risk of contamination. This device utilizes canistered oxygen sources. This device also would be rendered inoperable under the conditions anticipated by the present invention.

Therefore, there is a need for portable ventilators that overcome the disadvantages of the existing stationary ventilators.

The following portable ventilators address some of the needs discussed above. U.S. Patents 6,152,135, 5,881,722 and 5,868,133 to DeVries, et al., discloses a portable

ventilator device that utilizes ambient air through a filter and a compressor system. The compressor operates continuously to provide air only during inspiration. The DeVries, et al., devices are utilized in hospital settings and are intended to provide a patient with mobility when using the ventilator. Since these devices are not directed to on-site emergency use, they provide closed loop control, sophisticated valve systems and circuitry that would render them inoperable under the types of emergency conditions anticipated by the present invention.

The references cited above recognize the need for portable ventilators that provide a consistent breathing circuit. As is the case with most portable ventilators, these devices provide breathing circuits including valve systems and an oxygen source. However, these devices lack the means by which they can be quickly facilitated in emergency situations where there are no stationary sources of power. Secondly, most of these devices depend on canister-style oxygen sources, which are cumbersome, and lessen the ability of the ventilators to be truly portable. Thirdly, the prior art ventilators do not provide breathing circuits that can be continuously used in the absence of stationary power sources. These and other drawbacks are

overcome by the present invention as will be discussed, below.

SUMMARY OF THE INVENTION

It is therefore an objective of this invention to provide a portable ventilator that provides short-term ventilatory support.

It is another objective of the present invention to provide a portable ventilator that includes a pneumatic subsystem, a power subsystem and a sensor subsystem.

It is another objective of the present invention to provide a portable ventilator wherein the pneumatic subsystem includes two dual head compressor for increased air output.

It is another objective of the present invention to provide a portable ventilator wherein the pneumatic subsystem includes an accumulator.

It is another objective of the present invention to provide a portable ventilator that is a disposable one-use device having an indefinite shelf life.

It is also another objective of the present invention to provide a portable ventilator that includes a pneumatic subsystem, a power subsystem, a control subsystem and an alarm subsystem.

It is another objective of the present invention to provide a portable ventilator wherein the pneumatic subsystem includes one dual head compressor for increased air output and a means for relieving air manifold pressure with a single head compressor, thereby eliminating the need for an accumulator.

It is another objective of the present invention to provide a portable ventilator wherein the power subsystem includes a battery source and a jack that allows the ventilator to access an external power source, where the battery or the external power source is used to power the pneumatic, control and alarm subsystems.

It is another objective of the present invention to provide a portable ventilator wherein the power subsystem also includes a power conditioning circuit to eliminate fluctuating voltages to the control subsystem.

It is also another objective of the present invention to provide a portable ventilator wherein the control subsystem includes a timing circuit and a relay switch to control the on-off cycle of the dual-head and single head compressors.

It is also another objective of the present invention to provide a portable ventilator wherein the alarm subsystem is capable of visually indicating repairable, non-repairable and patient based problems as well as an audible alarm.

It is another objective of the present invention to provide a portable ventilator that is a disposable one-use device or a refurbished device having an indefinite shelf life.

These and other objectives have been described in the detailed description provided below.

DESCRIPTION OF THE DRAWINGS

Figure 1 is a schematic of the portable ventilator, the pneumatic subsystem, the power subsystem and the sensor subsystem.

Figure 2 is a schematic of the pneumatic subsystem shown in **figure 1**.

Figure 3 is a schematic of the power subsystem shown in **figure 1**.

Figure 4 is a schematic of the sensor subsystem shown in **figure 1**.

Figure 5 is a drawing of the portable ventilator shown in **figure 1**.

Figure 6 is a schematic of the portable ventilator, the pneumatic subsystem, the power subsystem, the control subsystem and the alarm subsystem.

Figure 6a is a drawing of the portable ventilator shown in **figure 6**.

Figure 7 is a schematic of the pneumatic subsystem shown in **figure 6.**

Figure 8 is a schematic of the power subsystem shown in **figure 6.**

Figure 9 is a schematic of the control subsystem shown in **figure 6.**

Figure 9a is a graph of the dual head compressor on-off cycle.

Figure 9b is a graph of resistors and capacitor charging and discharging timing cycle.

Figure 9c is a graph of the output of the timing circuit.

Figure 9d is a graph of the higher power on-off cycle from the relay switch to the dual head compressor.

Figure 9e is a graph of the higher power on-off cycle from the relay switch to the single head compressor.

Figure 10 is a schematic of the alarm subsystem shown in **figure 6.**

DETAILED DESCRIPTION OF THE EMBODIMENTS

The present invention is a portable ventilator that provides short-term ventilatory support to one or more patients for the management of trauma or respiratory paralysis. As shown in **figure 1,** the portable ventilator **V** assures consistent tidal volume and respiratory rate and

provides hands free operational capabilities. The portable ventilator **V** is a fully functional multi-mode device suited for field hospital or forward surgical units, where experienced personnel can utilize the multi-mode capabilities unique to this device. Portable ventilator **V** is also suitable for use by untrained personnel, and in particularly useful in resource-limited environments. Additionally, the portable ventilator **V** can be configured as a disposable one-use device that has an indefinite shelf life.

Also in **figure 1**, the portable ventilator **V** of the present invention includes a pneumatic subsystem **N**, a power subsystem **P**, and a sensor subsystem **S**. Each of these systems shall be described below.

The pneumatic subsystem:

As shown in **figure 2**, the pneumatic subsystem **N** includes two dual head air compressors **1a** and **1b** for increased air output. Ambient or NVC filtered air is drawn into the dual head compressors **1a** and **1b** and compressed. The compressed air exits **1a** and **1b** and enters into the accumulator tank **2**. An accumulator tank **2** is connected to each of the compressors **1a** and **1b** to act as a pneumatic holding area for the combined outputs (4 in total) of

compressors **1a** and **1b**. The accumulator tank **2** overcomes the inconsistent nature of the phasing of the pressure waves inherent with dual head air compressors and prevents compressors **1a** and **1b** outputs from canceling each other. The accumulator tank **2** is further connected to a connector system **3**. Since the compressors **1a** and **1b** function as constant-flow rates over a wide range of physiologic pressures, the connector system **3** provides constant, total airflow through the accumulator **2** to the user, for a necessary period of time. The periods of time are controlled through a timing circuit **T** that is part of a logic board **B**.

<u>The logic board:</u>

The logic board **B** includes timing circuit **T** and is connected to the power subsystem **P**. Logic board **B** controls power to compressors **1a** and **1b** in order to turn **1a** and **1b** on and off. Duration of the on-time of compressors **1a** and **1b** determines the amount of air that is delivered to the user. The logic board **B** utilizes analog logic and does not require microprocessor control. The logic board **B** is also connected to the sensor subsystem **S**.

The sensor subsystem:

As shown in **figure 3**, the portable ventilator **V** includes a sensor subsystem **S** that provides critical care monitoring and support critically ill patients in the emergency situations. The sensor subsystem **S** includes an airflow sensor **4** that detects loss of connection of the portable ventilator **V** from the patient's face mask or endotracheal tube. The sensor subsystem **S** also includes an airway pressure sensor **5**. The pressure sensor **5** provides the desirable function of detecting the end of a previous breath (inhaled) in the user, so that air delivery can be delayed until the completion of the previous breath. An airflow sensor **6** is used to detect the cessation of exhalation of the previous breath if the scheduled start time for the next breath is not completed. The sensor subsystem **S** may be located within the ventilator **V** or be exterior to ventilator **V**.

The power subsystem:

As shown in **figure 4**, the power subsystem **P** of the portable ventilator **V** include disposable or rechargeable batteries **7** that are capable of operating under high capacity, wide temperatúre ranges and are compatible with the pneumatic subsystem **N** and the sensor subsystem **S**. In a

preferred embodiment, the portable ventilator **V** of the present invention utilizes conventional lead-acid rechargeable batteries **7**. The batteries **7** must provide at least 30 to 60 minutes of operating time.

<u>The portable ventilator</u>:

As shown in **figure 5**, the pneumatic subsystem **N** is connected to the sensor subsystem **S** and the power subsystem **P** and enclosed within housing **8** of the portable ventilator **V**. Housing **8** includes an rigid frame structure **8a** that is made of either plastic or metals and capable of withstanding physical and mechanical pressures. Portable ventilator **V** includes an input port **8b** that allows rechargeable batteries **7** to be powered using an external power source or an AC power source. Alternatively, batteries **7** may include disposable type batteries.

Housing **8** also a recessed control panel **8c**. Control panel **8c** includes ports for providing air to the user through known means. The panel **8c** also includes a switch for selecting desired air flow rates, an on/off switch, and can include a switch for recharging the batteries **7**. The control panel **8c** is recessed to prevent damage to any instrumentation positioned thereon.

The portable ventilator **V** of the present invention implements controlled ventilation and assists control ventilation to a patient. Example 1 below shows functionality and performance of two portable ventilators V described above.

<u>Example 1</u>:

The Sekos 2 and 3 ventilators were tested. All tidal volumes, respiratory rates and other parameters were within ±10% of the settings existing on the ventilator **V**.

PERFORMANCE PARAMETER	SEKOS 2	SEKOS 3
APPROX. WEIGHT (lb0	12	<6
APPROX. SIZE (in.)	10.75W X 9.75D X 7 H	5.7W X 11.5D X 3.5H
PHYSICAL VOLUME (in^3)	733	230
BATTERY TYPE/SIZE	3.4 Ah lead acid	1.3 Ah lead acid
OPERATING LIFE (h)	1.5-3	0.3-1
COMPRESSORS	2	2
CONTROLLABLE I:E RATIO	No	No
RESP. RATE ADJUSTMENT (bpm)	6-30	10 OR 20 ONLY
TIDAL VOLUME (ml)	200-1200	300, 900, OR 1200
MAX MINUTE VOLUME (L/m)	20 (NOT YET TESTED)	20 (NOT YET TESTED)
INSPIRATORY FLOW MEASUREMENT	No	No
EXPIRATORY FLOW MEASUREMENT	Yes	Yes

The portable ventilators tested above, have been shown to be superior in performance to traditional "ambu-bags".

These and other portable ventilators having the features discussed above are within the scope of this invention.

The present invention includes a preferred embodiment as shown in **figure 6**. The portable ventilator $\mathbf{V_2}$, as shown in **figure 6**, includes a pneumatic subsystem $\mathbf{N_2}$, a power subsystem $\mathbf{P_2}$, a control subsystem $\mathbf{C_2}$ and an alarm subsystem $\mathbf{A_2}$.

The portable ventilator $\mathbf{V_2}$ as shown in **figure 6(a)** includes a hard shell housing **100** having an exterior surface **100a** and an interior surface **100b**.

<u>The pneumatic subsystem $\mathbf{N_2}$</u>:

As shown in **figure 7**, the pneumatic subsystem $\mathbf{N_2}$ includes at least one dual head air compressor **101** for increased air output and a single head compressor **102** for closing a flutter valve **103**. The pneumatic subsystem $\mathbf{N_2}$ is responsible for the inhalation and exhalation cycles of the portable ventilator $\mathbf{V_2}$. During the inhalation cycle, ambient air **a** is drawn into the dual head compressor **101** through the air input port **104**. Ambient air **a** may also be passed through an NBC filter **NBC** to remove contaminants, before passing through air input port **104**. Alternatively, a small adapter (not shown) may be connected to the air input port **104** to allow the ventilator $\mathbf{V_2}$ to operate by drawing air **a**

from a purified source (not pictured). Upon entering the portable ventilator **V_2**, ambient air **a** is divided into two air flow paths by y-shaped medical grade tubing **105.** The tubing **105** may also be pre-manufactured plastic or metal. As is understood by one of ordinary skill in the art, tubing **105** includes all necessary fittings and attachments. Additionally, tubing **105** may be an integral part of an interior portion **100b** of the hard shell housing **100,** shown in **figure 6a.** Ambient air **a** enters the dual head compressor **101,** from tubing **105,** through dual-head compressor input ports **101a** and **101b**. Dual head compressor **101** compresses ambient air **a.** It is important to note that combination of using a dual head compressor **101** with a single head compressor **102** is critical to the portable ventilator **V_2** of the preferred embodiment of this invention as disclosed in **figures 6** through **10**. It is also important to note that multiple single head compressors in place of the dual head compressor **101,** as disclosed in the preferred embodiment of **figures 6** through **10,** are outside the scope of this present invention. This is because dual-head compressors provide for increased efficiency and smaller size. This factor is essential to the proper design and function of the portable ventilator **V_2**.

Example 2:

For an equivalent tidal volume output: Dual Head Compressor: weight - 14.2 oz, size - 28.9 cubic inches.

2 Single Head Compressors: weight - 20.4 oz, size - 32.0 cubic inches.

Dual-head compressors draw in outside air and increase pressure within, to allow for the proper tidal volumes to be pushed through a small amount of space. Using the ideal gas law PV=nRT, where (P) = pressure, (V) = volume, (n) = number of molecules, (R) = gas law constant, and (T) = temperature, the values nRT must remain constant when dual head compressor **101** is operational. Thus, as necessitated by the proper operation of ventilator $\mathbf{V_2}$, obtaining particular volumes (V) of air from the environment into a small, fixed volume of the ventilator $\mathbf{V_2}$, requires that the pressure (P) of the air **a** must be increased to keep nRT the same. The increased pressure of air **a** forces the air **a** through the ventilator $\mathbf{V_2}$ into the lungs of the patient **H**. This is due to the tendencies of fluids, here the compressed air **a**, to flow from the area of greater pressure of the ventilator $\mathbf{V_2}$ to the area of lower

pressure of the lungs of the patient **H**, thereby filling them.

As shown in **figure 7**, compressed air **a** exits the compressor **101** through compressor output ports **101c** and **101d** and into the air manifold **106**. Air manifold **106** is manufactured from plastic or metal. Air manifold **106** may also be an integral part of the interior portion **100b**. As is understood by one of ordinary skill in the art, air manifold **106** includes all necessary fittings and attachments. A pressure sensor **107** is connected to the air manifold **106** to monitor the pressure of air **a** delivered to the patient **H**. The pressure sensor **107** gauges the air pressure of compressed air **a** within air manifold **106**. When air **a** exceeds a known threshold, the dual head compressor **101** is stopped and the single head compressor **102** is started, and air is no longer delivered to the patient **H**, as discussed below. As shown in **figure 7**, the air manifold **106** is also connected to the flutter valve **103**. Flutter valve **103** allows compressed air **a** to enter through input port **103a** and be delivered to the patient **H** through bi-directional port **103b**. When compressed air **a** is being delivered to the patient **H** through bidirectional port **103b**, exhale port **103c** remains closed. When the patient **H** exhales however, the input port **103a** is closed off, and exhale port

103c is open to allow exhaled air to be removed from the portable ventilator $\mathbf{V_2}$. The exhalation cycle is described below. Compressed air **a**, that is delivered to the patient **H**, passes through medical grade tubing **108**, flutter valve **103** and further through medical grade tubing **109** that is connected to the patient **H** through valve port **110**. It is important to note that tubing **108** is integral to air manifold **106**, and is shown in **figure 7** as a separate element for descriptive purposes. Medical grade tubings **108** and **109** may also be pre-manufactured plastic or metal. As is understood by one of ordinary skill in the art, tubings **108** and **109** include all necessary fittings and attachments. Tubings **108** and **109** may be integral to interior portion **100b**. A standard medical grade, patient endotracheal tube (not shown) or tubing to a respiratory mask (not shown) is connected between the portable ventilator $\mathbf{V_2}$ and the patient **H** at patient valve port **110**.

During the exhalation cycle, exhaled air $\mathbf{a_e}$ is returned from the patient **H** through the patient valve port **110**, tubing **109** and the bi-directional port **103b**. The single head compressor **102** causes flutter valve **103** to close input port **103a**, thereby directing the exhaled air $\mathbf{a_e}$ into exhaust port **103c**. Exhaled air $\mathbf{a_e}$ passes from exhaust port **103c** into medical grade tubing **111**. Tubing **111** may be

premanufactured plastic or metal and may be integral to interior portion **100b**. As is understood by one of ordinary skill in the art, tubing **111** includes all necessary fittings and attachments. Tubing **111** includes a t-junction **111a** that directs the exhaled air $\mathbf{a_e}$ into a second pressure sensor **112**. Second pressure sensor **112** verifies whether patient **H** is exhaling. In an alternate embodiment, t-junction **111a** and pressure sensor **112** can be replaced with an in-line flow sensor (not shown). The exhaled air $\mathbf{a_e}$ is directed to a patient exhale port **115**, positioned on the ventilator housing **100**. Prior to reaching the exhale port **115**, the exhaled air $\mathbf{a_e}$ is directed through an in-line capnography chamber **113**. The capnography chamber **113** is used to detect the presence of exhaled CO_2 in exhaled air $\mathbf{a_e}$. The exhaled air $\mathbf{a_e}$ travels from the capnography chamber **113** through medical grade tubing **114**. Tubing **114** may be premanufactured plastic or metal and may be integral to interior portion **100b**. As is understood by one of ordinary skill in the art, tubing **114** includes all necessary fittings and attachments. An additional colorimetric or chemical capnography sensor **CS** may be connected externally to portable ventilator $\mathbf{V_2}$ at exhale port **115**, to further monitor ventilation efficiency. As shown in **figure 7**, the single head compressor **102**, is connected to the flutter

valve **103** and the air manifold **106** through medical grade tubing **116**. It is important to note that tubing **116** is integral to air manifold **106**, and is shown in **figure 7** as a separate element for descriptive purposes. Tubing **116** may be premanufactured plastic or metal and may be integral to interior portion **100b**. As is understood by one of ordinary skill in the art, tubing **116** includes all necessary fittings and attachments. The single head compressor **102** operates only when the dual-head compressor **101** is not running. The single-head compressor **102** is used in this manner to ensure that the flutter valve input port **103a** remains fully closed and the exhaust port **103c** to be fully open in the exhalation cycle. This alternating operation of the dual head compressor **101** and the single head compressor **102** allows for dead volumes of air located in air manifold **106** to be evacuated through tubing **116**, medical grade tubing **117** and exhaust port **118**, between the inhalation cycles. Tubing **117** may be premanufactured plastic or metal and may be integral to interior portion **100b**. As is understood by one of ordinary skill in the art, tubing **117** includes all necessary fittings and attachments. It is important to note that the single head compressor **102** functions to mechanically close flutter valve **103**. This mechanism is preferred over electronically controlled

valves, as they lead to pressure losses. This mechanism is preferred over other venting systems and pressure relief valves to reduce loss of inspiration air and pressure gradients. Secondly, use of the single head compressor **102** forcibly pulls air **a** out of air manifold **106**, thereby allowing for the next inhalation cycle to begin unimpeded by dead air within air manifold **106**. Thirdly, the single head compressor **102** provides a brief instance of negative pressure during the closure of input port **103a** that assists the patient **H** to exhale. In addition, the operation of this dual head compressor **101** and the single head compressor **102** precludes the use of the accumulator **2**, as discussed in the embodiments of **figure 1**, above. In an alternate embodiment, single head compressor **102**, tubing **117** and exhaust port **118** can be used to relieve pressure and/or heat buildup within the portable ventilator $\mathbf{V_2}$. Exhaust port **118** also protects the portable ventilator $\mathbf{V_2}$ from contamination in extreme environmental hazards, as well as contamination from water, dust, mud, etc.

It is important to note that the exhaust port **118** is positioned away from exhaust port **115** so as not to alter capnography measurements obtained from capnography sensors **113** and **CS**.

The power subsystem $\mathbf{P_2}$:

The power subsystem $\mathbf{P_2}$, as shown in **figure 8**, is discussed below. The power subsystem $\mathbf{P_2}$ provides power to the portable ventilator $\mathbf{V_2}$. The power subsystem $\mathbf{P_2}$ includes a battery source **201** and a power jack **202** that accepts an external power source **EP**. A 12-14 volt rechargeable battery is preferred as the battery source **201.** However, replaceable batteries may also be utilized. Power jack **202** is connected to electronic circuit **203** that is further connected to the battery source **201.** The electronic circuit **203** accepts power from the external power source **EP** through the power jack **202** to regulate voltage necessary to recharge battery source 201 and/or bypass battery source **201.** When an external power source **EP** is connected to the power jack **202,** the by-pass from the electronic circuit **203** allows the portable ventilator $\mathbf{V_2}$ to operate if battery **201** is missing, inoperational or recharging. Power is directed from either the battery **201** or the electronic circuit **203** into a power switch **204.** When the power is turned on, it is directed from the power switch **204** to a voltage regulator circuit **205** that provides power for the subsystems within the ventilator $\mathbf{V_2}$.

The power subsystem $\mathbf{P_2}$ utilizes the voltage regulator circuit **205** to eliminate fluctuating voltages to the

control subsystem **C_2**. For components in the control and alarm subsystems **C_2** and **A_2**, respectively, that require a lower voltage, a second voltage regulator circuit **206** is utilized. Additionally, the power subsystem **P_2** provides driving voltage through the control subsystem **C_2** to the dual head compressor **101** and the single head compressor **102** of the pneumatic subsystem **N_2**.

<u>The control subsystem **C_2**:</u>

As discussed under the pneumatic subsystem **N_2** above, the on-off cycle between dual head compressor **101** and single head compressor **102** is critical to the operation of the preferred embodiment as shown in **figure 6**. As shown in **figure 9**, the control subsystem **C_2** includes a timing circuit **401** that is used to control a mechanical relay switch **402** that in turn determines the on/off cycle between dual head compressor **101** and the single head compressor **102**. The relay is configured as an electronically controlled single-pole double-throw switch **402**. In a preferred embodiment, timing circuit **401** is a "555" circuit. The relay switch **402** is in turn connected to the single head compressor **102** of the pneumatic subsystem **N_2** through a relay switch bar **402a** and a first connector position **402b**. Relay switch **402** and relay switch bar **402a** are preferably mechanical. The

relay switch **402** is also connected to the dual head compressor **101** through the switch bar **402a** and second connector position **402c**. The timing circuit **401** is connected to a relay control **402d**, that is used to move the relay switch bar **402a** between first connector position **402b** and second connector position **402c**, based upon a breath-timing cycle generated by the timing circuit. The breath-timing cycle is discussed below. The timing circuit **401** is also connected to a capacitor **403**, a first resistor **404** and a second resistor **405**. Second resistor **405** is in turn connected to the power subsystem P_2. The connection between the power subsystem $\mathbf{P_2}$ and the pneumatic subsystem $\mathbf{N_2}$ is not shown in **figure 9**.

The breath-timing cycle is defined by the respiratory rate and the tidal volume, the values for which have been selected in accordance with American Medical Association guidelines.

As shown in **figure 9a**, $\mathbf{t_1}$ represents the desired on time of compressor **101**, correlating to the inhalation time, and $\mathbf{t_2}$ represents the desired off time of compressor **101**, correlating to the exhalation time. The sum of the inhalation and exhalation times ($\mathbf{t_1}$ + $\mathbf{t_2}$) is one complete breath-timing cycle.

The respiratory rate is the number of complete breath-timing cycles per minute. The tidal volume is determined by the amount of air delivered during the inspiration phase in one breath-timing cycle. Tidal volume is the product of the flow rate of the compressor **101** by the on time $\mathbf{t_1}$ of compressor **101**. Therefore:

(1) $\mathbf{t_1} = TV/f$

where TV= tidal volume, f=flow rate of compressor **101**;

(2) $\mathbf{t_1} + \mathbf{t_2} = 60$ seconds/RR

where RR=respiratory rate, the number of breaths per minute;

(3) $\mathbf{t_2} = 60/RR - \mathbf{t_1} = 60/RR - TV/f$.

The values for $\mathbf{t_1}$ and $\mathbf{t_2}$ are thus determined by using the AMA's respiratory rate and tidal volume guidelines, as well as the flow rate of compressor **101**. Diode **406** is used to allow the possibility that $\mathbf{t_1}$ less than $\mathbf{t_2}$.

As would be understood by one of ordinary skill in the art, the capacitor **403**, first resistor **404** and second resistor **405** form a charging and discharging timing circuit. In the present invention, as shown in **figure 9b**,

the charge cycle duration is selected to be equal to the desired inhalation time $\mathbf{t_1}$. The discharge timing cycle is selected to be equal to the determined exhalation time $\mathbf{t_2}$. Thus:

(4) $\mathbf{t_1} = .693(r_1 + r_2)c_1$ and

(5) $\mathbf{t_2} = .693(r_2)c_1$;

where r_1 is the value of the first resistor **404**, r_2 is the value of the second resistor **405** and c_1 is the value of the capacitor **403**.

Because the output of the charging and discharging circuit is indeterminate with respect to an on or off state of compressor **101**, timing circuit **401** is utilized to establish a clear demarcation of on and off states, as shown in **figure 9c**, triggered by the output of the charging and discharging circuit.

It is important to note that timing circuit **401** is not powerful enough to operate compressors **101** and **102** directly. Therefore, the relay **402** is used where the output of timing circuit **401**, as shown in **figure 9c**, is the control input to the relay **402**. A resistor **407** is used to prevent an electrical short, when the output of timing circuit **401** is on.

As shown in **figure 9d**, the output of the charging and discharging circuit from timing circuit **401** controls the relay **402** such that the on-cycle of circuit **401** causes the relay **402** to create a pathway to deliver a high power on-cycle to dual head compressor **101**.

As shown in **figure 9e**, the off-cycle of timing circuit **401** causes the relay **402** to create a pathway to single head compressor **102**. The on-cycle of compressor **101** and off cycle of compressor **102** make up the on-off cycle discussed above.

It is also important to note that the timing characteristics, as shown in **figures 9c** and **9d**, must correspond to the desired timing characteristics in **figure 9a** for the proper operation of portable ventilator $\mathbf{V_2}$.

<u>The alarm subsystem $\mathbf{A_2}$:</u>

As shown in **figure 10**, the alarm subsystem $\mathbf{A_2}$ includes a light alarm suppression switch **501** connected to a repairable LED indicator **502**, a non-repairable LED indicator **503** and a patient problem LED indicator **504**. The LED indicators **502**, **503** and **504** are configured to indicate repairable problems, non-repairable problems, and patient based problems, respectively, within the portable ventilator $\mathbf{V_2}$. The LED indicators **502**, **503** and **504** are

positioned on the outer surface **100a** of hard shell **100** of portable ventilator $\mathbf{V_2}$. The alarm suppression switch **501** is accessible to the user **U** and used to disengage LED alarms **502, 503** and **504** when necessary. An audible alarm suppression switch **505** connected to an audible alarm switch **506.** The audible alarm switch **506** is positioned on the outer surface **100a** of hard shell **100.** The audible alarm suppression switch **505** is accessible to the user **U** and used to disengage audible alarm **506** when necessary.

A low voltage detect circuit **507** is connected to the battery **201** and the power switch **205** of the power subsystem $\mathbf{P_2}$ to indicate when voltage is too low. Low voltage detect circuit **507** is also connected to the light alarm suppression switch **501** and repairable LED indicator **502** to denote a repairable problem to the user **U.** The low voltage detect circuit **507** is also connected to the audible alarm suppression switch **505** and the audible alarm to indicate a sound-based alarm to the user **U.**

A missing pulse/device/component failure detect circuit **508** is connected to the control subsystem $\mathbf{C_2}$. The missing pulse/device/component failure detect circuit **508** is also is also connected to the light alarm suppression switch **501** and non-repairable LED indicator **503** to denote a non-repairable problem to the user **U,** ie portable

ventilator **V_2** must be replaced. The missing pulse/device/component failure detect circuit **508** is also connected to the audible alarm suppression switch **505** and the audible alarm to indicate a sound-based alarm to the user **U**.

Carbon dioxide detect circuit **509** is connected to a carbon dioxide event counter **510** and a carbon dioxide event trigger **511**. The circuit **509**, counter **510** and trigger **511** is connected to the capnography sensor **113** of the pneumatic subsystem **N_2** to indicate insignificant carbon dioxide concentrations in exhaled air **a_e**. The carbon dioxide event trigger **511** is further connected to the light alarm suppression switch **501** and patient problem LED indicator **502** to denote a improper connection or patient distress to the user **U**. The circuit **509**, counter **510** and trigger **511** are also connected to the audible alarm suppression switch **505** and the audible alarm to indicate a sound-based alarm to the user **U**.

An exhale airflow detect circuit **512** is connected to an exhale event counter **513** and an exhale event trigger **514**. The exhale circuit **512**, event counter **513** and event trigger **514** is connected to the pressure sensor **112** of the pneumatic subsystem **N_2**. The exhale event trigger **514** is further connected to the light alarm suppression switch **501**

and patient problem LED indicator **502** to denote a improper connection or patient distress to the user **U**. The exhale circuit **512**, event counter **513** and event trigger **514** are also connected to the audible alarm suppression switch **505** and the audible alarm to indicate a sound-based alarm to the user **U**.

An inspiration pressure detect circuit **515** is connected to an inspiration event counter **516** and inspiration event trigger **517** to generate an alarm response when the ambient air, **a**, pressure is too high or too low. The inspiration circuit **515** is connected to the pressure sensor **107** of the pneumatic subsystem $\mathbf{N_2}$. The inspiration event trigger **517** is further connected to the light alarm suppression switch **501** and patient problem LED indicator **502** to denote a improper connection or patient distress to the user **U**. The inspiration pressure detect circuit **515**, inspiration event counter **516** and inspiration event trigger **517** are also connected to the audible alarm suppression switch **505** and the audible alarm to indicate a sound-based alarm to the user **U**. This inspiration pressure detect circuit **515** can also cause the relay control switch **402d** to immediately switch from operating the dual head compressor **101** to operating the single head compressor **102** when a

preset pressure threshold is exceeded, to prevent harm to patient **H**.

What is claimed is: